REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1996

3. REPORT TYPE AND DATES COVERED
Progress Report - period ended 3/31/96

4. TITLE AND SUBTITLE
Quantitative Utilization of Lagrangian Data in Numerical Models.

5. FUNDING NUMBERS
N00014-95-1-0803

6. AUTHOR(S)
A.D. Kirwan, Principal Investigator

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, VA 23508-0369
Department of Oceanography

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 North Quincy St.
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified; Unlimited

19970505 117

13. ABSTRACT *(Maximum 200 words)*
The long range goal of this project was to quanify the dynamical mechanism responsible for the exchange of mass, momentum and energy between the coastal and open oceans. Nonlinear mechanisms operating on sub-grid scales, dynamically consistent and quantitative methods for interpreting quasi-Lagrangian data, and nonlinear/nonquasigeostrophic flows were the main study. The first was to determine the role of secondary circulation on the exchange between the coastal and open oceans. The second was to determine how ocean eddies produce super inertial fluctuations in hydrodynamic fields. As documented in the scientific literature, considerable progress was made on these questions. It is expected that this research contributes to improved parameterizations of sub-grid scale processes and to efficient utilization of quasi-Lagrangian data.

14. SUBJECT TERMS
Secondary circulation, sub-grid scales, quasi-Lagrangian, particle in cell

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

DTIC QUALITY INSPECTED 1

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements.***

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	**PR**	- Project
G	- Grant	**TA**	- Task
PE	- Program Element	**WU**	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

PROJECT TITLE: Quantitative Use of Lagrangian Data in Numerical Models

PRINCIPAL INVESTIGATORS: A. D. Kirwan, Jr. and B. L. Lipphardt, Jr.
INSTITUTION: Center for Coastal Physical Oceanography
Old Dominion University
ADDRESS: 768 West 52nd Street, Norfolk, Virginia 23529
TELEPHONE (voice): (804) 683-4945
TELEPHONE (fax): (804) 683-5550
EMAIL: adk@ccpo.odu.edu, bruce@ccpo.odu.edu

CONTRACT NUMBER: N00014-95-1-0803
CONTRACT START, END DATES: 1 April 1995, 30 September 1996
SUMMARY SUBMISSION DATE: November 14, 1995

OBJECTIVE:

An unprecedented amount of Lagrangian data is now being collected by oceanographers. The general feeling is that such data are important for an accurate description of ocean circulation. Regrettably, little hard analysis has gone into deployment strategies and even less into quantitative use of Lagrangian data after it has been collected. This is unfortunate, since such data can enhance numerical modeling efforts through data assimilation, which makes explicit use of the data's Lagrangian character. These data can also be used to assess a model's ability to predict the evolution of transient events.

The long range objective of this project is to develop theoretically based quantitative procedures for utilizing Lagrangian data for both of these applications. The focus of this phase of the effort will be on using both surface and subsurface Lagrangian data for a quantitative assessment of circulation models.

APPROACH:

The approach used here is an improvement of that used by Eremeev *et al.* (*Jour. Geophys. Res. 97*: 9733-9753, 1992). This is summarized briefly here.

The basis for the procedure is a general Eulerian representation of any hydrodynamic field Γ^r as:

$$\Gamma^r(\mathbf{x},\eta,t) = \sum_{k=1}^{K} A_k^r(\eta,t)\,\Gamma_k^r(\mathbf{x},t) \tag{1}$$

Here, the superscript r could represent components of the velocity field and η is a surface that is a characteristic of either a model or the Lagrangian observations. This might be depth for a numerical model, and an isopycnal or isobaric surface for data. The Lagrangian representation of the same field simply replaces the horizontal position $\mathbf{x}$ with the path data $\mathbf{x}^p$ for Lagrangian probe p.

The key issue is the specification of the basis function Γ_k^r in (1). A number of

options are available, but the one most appropriate for this effort is to utilize a representation of the velocity field as:

$$\mathbf{u} = \nabla \times [\mathbf{n}\psi + \nabla \times (\mathbf{n}\phi)] \tag{2}$$

where $\mathbf{n}$ is normal to η. Projection of $\mathbf{u}$ and $\nabla \times \mathbf{u}$ onto η give:

$$\mathbf{n} \cdot \mathbf{u} = -\nabla \cdot [(\mathbf{n} \cdot \mathbf{n}) \nabla \phi - \mathbf{n}(\mathbf{n} \cdot \nabla\phi)]$$

$$\mathbf{n} \cdot (\nabla \times \mathbf{u}) = \mathbf{n} \cdot \nabla_H^2 (\mathbf{n} \times \nabla\phi) - \nabla \cdot [(\mathbf{n} \cdot \mathbf{n}) \nabla \psi - \mathbf{n}(\mathbf{n} \cdot \nabla\psi)] \tag{3}$$

The solution of (3) involves eigenfunctions of a Poisson problem which ensure no slip and no normal flow at the domain boundaries - typical numerical modeling constraints. These eigenfunctions are the basis functions Γ_k^r in (1). They can be calculated (with some difficulty and care) for any given model geometry. Once determined, they are used for both model output and observations.

PROGRESS SUMMARY:

We have been working on this project for less than 6 months, so only preliminary results are available. Although the approach described above is well documented in the literature, there is precious little experience with applications. In order to develop some focus, we elected to first apply the method to enclosed or nearly enclosed basins with a substantial amount of Lagrangian data. We have succeeded so far in the first task of developing numerical methods for calculating the eigenfunctions in (1) above for no slip boundary conditions.

APPLICATIONS:

When developed, this technology will impact naval operations in two ways. First, it will provide a powerful quantitative tool for comparing circulation model predictions with Lagrangian observations. This would assist in the interpretation of data from transient events and provide a more powerful method for assessing model performance than is currently used. Second, it will provide a means for assimilating drifter and float data into predictive models. Such a development would correct a long-standing problem with present assimilation methods, which don't take full advantage of the Lagrangian character of the data.

PROJECT TITLE: Quantitative Use of Lagrangian Data in Numerical Models
PRINCIPAL INVESTIGATORS: A. D. Kirwan, Jr. and B. L. Lipphardt, Jr.
SUBMISSION DATE: November 14, 1995

STATISTICS

a)	Papers published (refereed journals)	8
b)	Papers submitted (refereed journals)	5
c)	Books or chapters published	1
d)	Books or chapters submitted	0
e)	Technical reports/papers (non-refereed)	0
f)	Patents filed	0
g)	Patents granted	0
h)	Invited presentations at conferences	5
i)	Contributed presentations at conferences	14
j)	Undergraduate students	0
k)	Graduate students	2
l)	Post-docs	1
m)	Other professional personnel	1
n)	Female graduate students	0
o)	Minority graduate students	0
p)	Asian graduate students	0
q)	Female post-docs	0
r)	Minority post-docs	0
s)	Asian post-docs	0
t)	Instrumentation purchased	None
u)	Instrumentation fabricated	None
v)	Data submitted to national archives	None

CITATIONS

Papers published (refereed journals)

Kirwan, A. D. Jr. and B. L. Lipphardt, Jr., Coherent flows with near zero potential vorticity, *J. Mar. Sys., 4*, 95-115, 1993.

Mullen, C. P. and A. D. Kirwan, Jr. Surface flow structure of the Gulf Stream from composite imagery and satellite-tracked drifters, *Nonlinear Proc. Geophys., 1,* 64-71, 1994.

Holdzkom, J. J. II, S. B. Hooker and A. D. Kirwan, Jr., A comparison of a hydrodynamic lens model to observations of a warm core ring, *J. Geophys. Res., 100*, 15889-15897, 1995.

Eremeev, V. N., L. M. Ivanov, A. D. Kirwan, Jr., and T. M. Margolina, Amount of ^{137}Cs and ^{134}Cs radionuclides in the Black Sea produced by the Chernobyl disaster,"

J. Environ. Radiol., 27, 49-63, 1995.

Eremeev, V. N., L. M. Ivanov, A. D. Kirwan, Jr., and T. M. Margolina, Analysis of the Cesium pollution in the Black Sea by regularization methods," *Mar. Poll. Bull., 30*, 460-462, 1995.

Toner, M. and A. D. Kirwan, Jr., Periodic and homoclinic orbits in a toy climate model, *Nonlinear Proc. Geophys., 1*, 31-40, 1994.

Tsonis, A. A., G. N. Triantafyllou, J. B. Elsner, J. J.Holdzkom II, and A. D. Kirwan, Jr., An investigation of the ability of nonlinear methods to infer dynamics from observables, *Bul. Am. Met. Soc., 75*, 1623-1633, 1994.

Ivanov, L. M., A. D. Kirwan, Jr. and O. V. Melnichenko, Prediction of the stochastic behavior of nonlinear systems by deterministic models as a classical time passage probabilistic problem, *Nonlinear Proc. Geophys., 1*, 224-233, 1994.

Papers submitted (refereed journals)

Hooker, S. B., J. W. Brown, and A. D. Kirwan, Jr., Detecting 'dipole ring' separatrices with zebra palettes, *Trans. Geosci. Remote Sens.*, in press, 1995.

Hooker, S. B., J. W. Brown, A. D. Kirwan, Jr., R. P. Mied, and G. J. Lindemann, Kinematics of a warm-core dipole ring, *J. Geophys. Res.*, in press, 1995.

Kirwan, A. D. Jr., R. P. Mied, and B. L. Lipphardt, Jr., Rotating modons over isolated topography in a stratified ocean, *Dyn. Atmos. Oceans,* submitted.

Kirwan, A. D. Jr., C. E. Grosch and J. J. Holdzkom II, A particle-in-cell model for oceanographic flows, *J. Comp. Phys.*, submitted.

Eremeev, V. N., L. M. Ivanov, A. D. Kirwan, Jr., and T. M. Margolina, On the spectral reconstruction of scalar fields in oceanography, *J. Geophys. Res.*, submitted.

Books or chapters published

Kirwan, A. D. Jr., B. L. Lipphardt, Jr. and K. L. Gregory, Nonlinear Ocean Dynamics,The Oceans: Physical-Chemical Dynamics and Human Impact (S. K. Majumdar, E. W. Miller, G. S. Forbes, R. F. Schmalz, and A. A. Panah, editors), The Pennsylvania Academy of Science, 1994.

Invited presentations at conferences

Kirwan, A. D., Jr., Quasigeostrophic multipole vortices, Department of Mathematics, University of Stuttgart, Germany, May, 1994.

Kirwan, A. D., Jr., Modons: The inside story on ocean eddies, Brown University,

September, 1994.

Kirwan, A. D., Jr., Hydrodynamic aspects of oceanographic research, Department of Aerospace and Mechanical Engineering, Old Dominion University, October, 1994.

Kirwan, A. D., Jr., Ocean eddies: The inside story, Department of Physics, College of William and Mary, May, 1994.

Mied, R. P., C. Y. Shen, G. J. Lindemann, and A. D. Kirwan, Jr., Secondary circulations within internal bores, 20th General Assembly of the European Geophysical Society, Hamburg, Germany, April, 1995.

Contributed presentations at conferences

Holdzkom, J. J., II, A. D. Kirwan, Jr., C. E. Grosch, M. Zubair, and N. Kausar, Particle-in-cell simulations of coastal flows using massively parallel computers: Progress report, 1994 Ocean Sciences meeting, San Diego, California, February, 1994.

Kirwan, A. D., Jr., B. L. Lipphardt, Jr., and R. P. Mied, Multipole vortices in the Gulf of Mexico, 1994 Ocean Sciences meeting, San Diego, California, February, 1994.

Lipphardt, B. L., Jr., A. D. Kirwan, Jr. and R. P. Mied, Kinematics of dipoles from a baroclinic modon solution, 1994 Ocean Sciences meeting, San Diego, California, February, 1994.

Mullen, C. P., and A. D. Kirwan, Jr., Kinematics of the Gulf Stream from composite imagery and satellite-tracked drifters, 1994 Ocean Sciences meeting, San Diego, California, February, 1994.

Kirwan, A. D., Jr., B. L. Lipphardt, Jr., and R. P. Mied, Baroclinic rotating modons: Exact solutions to the nonlinear potential vorticity equations, 19th General Assembly of the European Geophysical Society, Grenoble, France, April, 1994.

Holdzkom, J. J., II and Kirwan, A. D., Jr., Dynamical systems aspects of a nonlinear hydrodynamic lens model, 19th General Assembly of the European Geophysical Society, Grenoble, France, April, 1994.

Hooker, S. B., J. W. Brown, A. D. Kirwan, Jr., R. P. Mied, and G. J. Lindemann, Forecasting the evolution of a warm core ring, 19th General Assembly of the European Geophysical Society, Grenoble, France, April, 1994.

Kirwan, A. D., Jr., C. E. Grosch, Holdzkom, J. J., II, N. Kausar, and M. Zubair, Particle-in-cell simulations on MPPS: Very large dynamical systems, 19th General Assembly of the European Geophysical Society, Grenoble, France, April, 1994.

Toner, M. and A. D. Kirwan, Jr., Topology of a chaotic two-dimensional climate model, 19th General Assembly of the European Geophysical Society, ¡Grenoble,

France, April, 1994.

Toner, M. and A. D. Kirwan, Jr., Parametric time dependence and bifurcation analysis of a climate model, 19th General Assembly of the European Geophysical Society, Grenoble, France, April, 1994.

Kirwan, A. D., Jr., J. J. Holdzkom II, C. E. Grosch, M. Zubair, and N. Kausar, Particle-in-cell simulations of oceanic flow, The International Conference on Nonlinear Dynamics and Pattern Formation in the Natural Environment (ICPF), Noordwijkerout, The Netherlands, July, 1994.

Kirwan, A. D., Jr., B. L. Lipphardt, Jr., and R. P. Mied, The dynamics of steady, rotating baroclinic multipole vortex systems, The International Conference on Nonlinear Dynamics and Pattern Formation in the Natural Environment (ICPF), Noordwijkerout, The Netherlands, July, 1994.

Holdzkom, J. J., II and A. D. Kirwan, Jr., Nonlinear behavior of a warm core ring, 20th General Assembly of the European Geophysical Society, Hamburg, Germany, April, 1995.

Kirwan, A. D., Jr. and B. L. Lipphardt, Jr., Geometric aspects of rotating multipole vortices, 20th General Assembly of the European Geophysical Society, Hamburg, Germany, April, 1995.